Laser diodes

Prerequisite/Recapitulations

- Light absorption and emission
- LEDs

Objectives

After completion of this lecture students/ learners will be able

- to understand the concept of Laser Diode, and
- applications of Laser Diode

Laser diodes

The name laser comes from the words Light Amplification by Stimulated Emission of Radiation. Lasers operate because of a phenomenon called stimulated emission that was first postulated by Albert Einstein before 1920. Although a number of media including gases liquids and amorphous solids can be used for lasers the first ones were realised in the 1960s using rubies. A helium-neon gas laser followed this in 1961 but it was not until 1970 that semiconductor laser diodes were made to run at room temperature by Hayashi. This represented the final step in research work that had been undertaken by a number of people and organisations over the years. It had required an in depth study of the properties of gallium Arsenide, the material that is used as the basis for many laser diodes and much work on the properties of the diode structures.

Laser diode technology is in widespread use today in many areas of the electronics industry.
Laser diode technology is now well established, with laser diodes providing a cost effective and reliable means of developing laser light.
With laser diodes being lending themselves to use in many areas of electronics from CD, DVD and other forms of data storage through to telecommunications links, laser diode technology offers a very convenient means of developing coherent light.

Introduction

Laser diode overview

Laser diodes are used in all areas of electronics from domestic equipment, through commercial applications to hash industrial environments. In all these applications laser diodes are able to provide a cost effective solution while being rugged and reliable and offering a high level of performance.

Laser diode technology has a number of advantages:

Power capability: Laser diodes are able to provide power levels from a few milliwatts right up to a few hundreds of watts.

Efficiency: Laser diode efficiency levels can exceed 30%, making laser diodes a particularly efficient method of generating coherent light.

Coherent light: The very nature of a laser is that it generates coherent light. This can be focussed to a diffraction limited spot for high density optical storage applications.

Rugged construction: Laser diodes are completely solid state and do not require fragile glass elements or critical set-up procedures. Accordingly they are able to operate under harsh conditions.

Compact: Laser diodes can be quite small allowing for laser diode technology to provide a very compact solution.

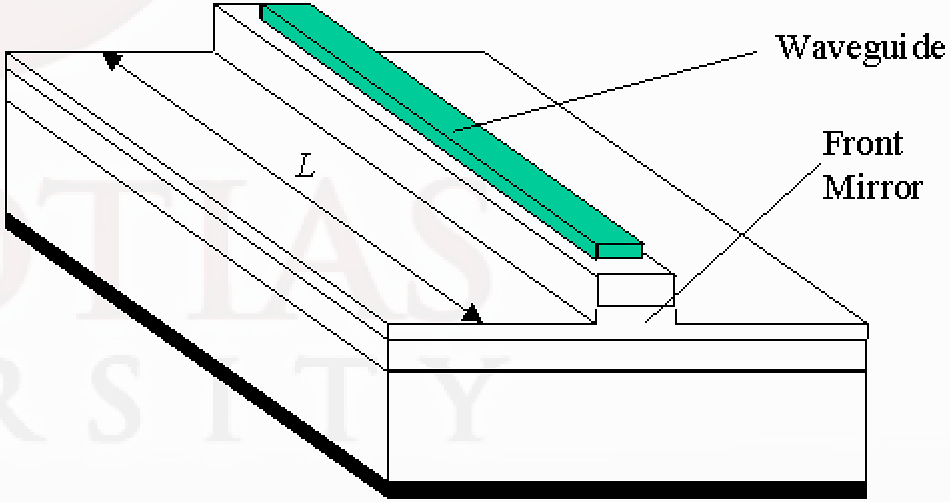
Variety of wavelengths: Using the latest technology and a variety of materials, laser diode technology is able to generate light over a wide spectrum. The use of blue light having a short wavelength allows for tighter focussing of the image for higher density storage.

Modulation: It is easy to modulate a laser diode, and this makes laser diode technology ideal for many high data rate communications applications. The modulation is achieved by directly modulating the drive current to the laser diode. This enables frequencies up to several GHz to be achieved for applications such as high-speed data communications.

https://www.electronics-notes.com/articles/electronic_components/diode/laser-diode-technology-what-is.php

Laser diodes

Laser diodes are very similar to LEDs since they also consist of a p-n diode with an active region where electrons and holes recombine resulting in light emission. However, a laser diode also contains an optical cavity where stimulated emission takes place. The laser cavity consists of a waveguide terminated on each end by a mirror. As an example, the structure of an edge-emitting laser diode is shown in Figure below. Photons, which are emitted into the waveguide, can travel back and forth in this waveguide provided they are reflected at the mirrors.



Structure of an edge-emitting laser diode.

Laser diodes

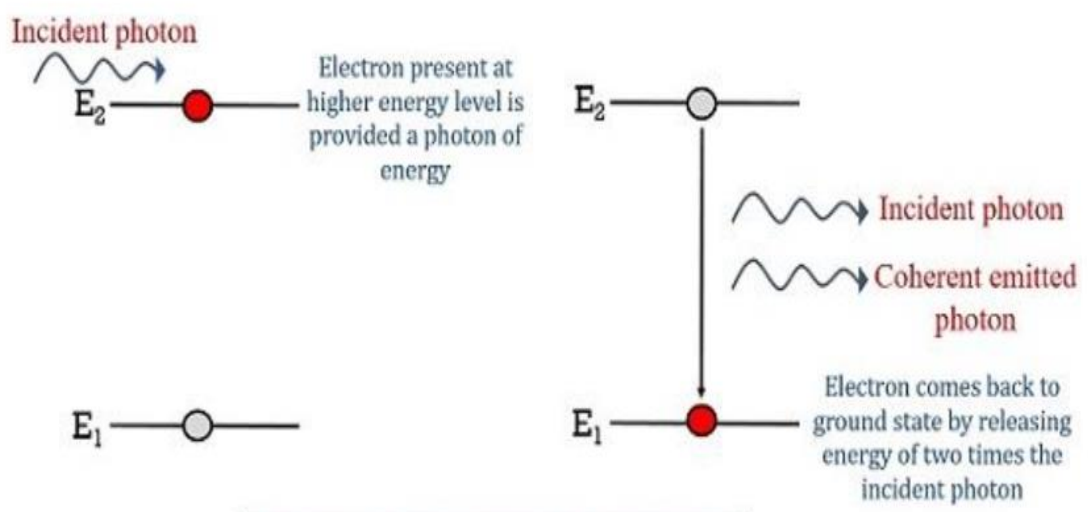
Laser diode theory basics

There are three main processes in semiconductors that are associated with light:

Light absorption: Absorption occurs when light enters a semiconductor and its energy is transferred to the semiconductor to generate additional free electrons and holes. This effect is widely used and enables devices like to photo-detectors and solar cells to operate.

Spontaneous emission: The second effect known as spontaneous emission occurs in LEDs. The light produced in this manner is what is termed incoherent. In other words the frequency and phase are random, although the light is situated in a given part of the spectrum.

Stimulated emission: Stimulated emission is different. A light photon entering the semiconductor lattice will strike an electron and release energy in the form of another light photon. The light in the waveguide is amplified by stimulated emission. Stimulated emission is a process where a photon triggers the radiative recombination of an electron and hole thereby creating an additional photon with the same energy and phase as the incident photon. This process is illustrated with Figure below. This "cloning" of photons results in a coherent beam.



Process of stimulated emission

Laser diode construction and operation

The term laser stands for light amplification by stimulated emission of radiation. Laser light is monochromatic, which means that it consists of a single color and not a mixture of colors. Laser light is also called coherent light, a single wavelength, as compared to incoherent light, which consists of a wide band of wavelengths. The laser diode normally emits coherent light, whereas the LED emits incoherent light. The symbols are the same as shown in Figure.

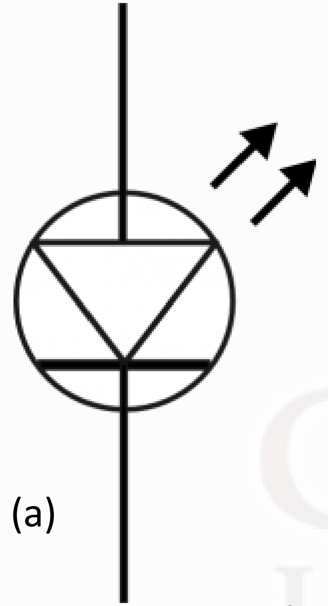


Fig : Laser Diode Symbol

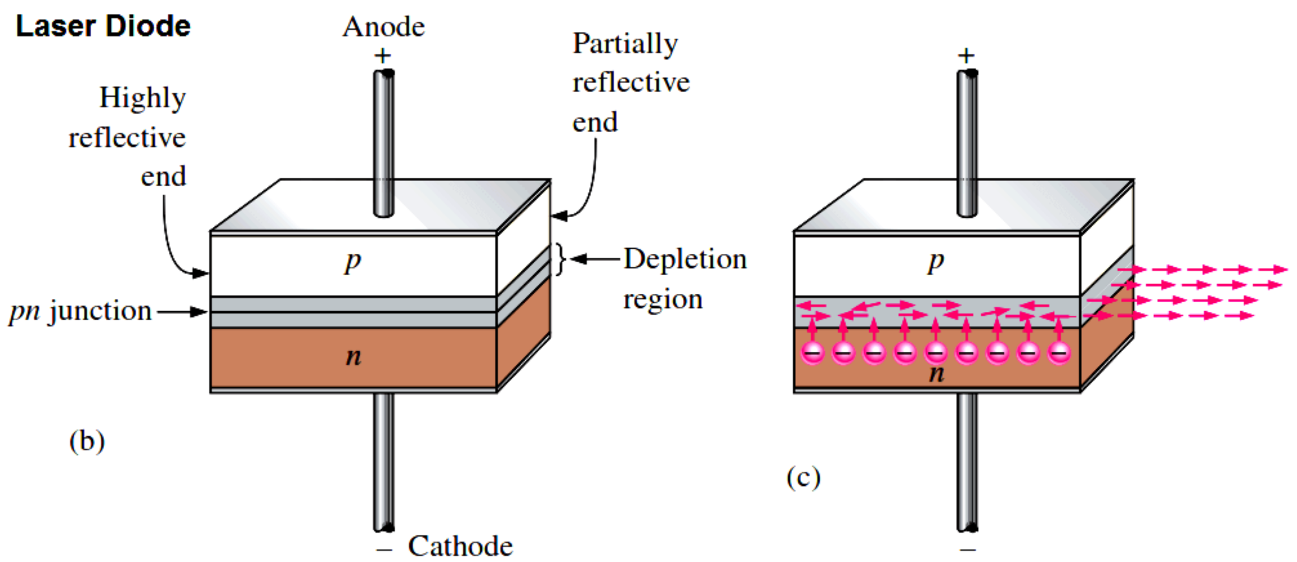
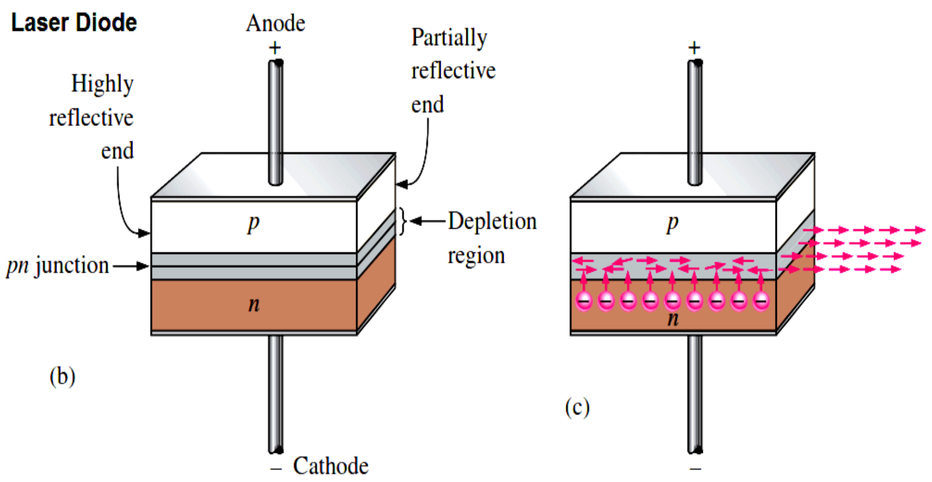


Fig : Basic laser diode construction and operation.

https://instrumentationtools.com/laser-diode-working-principle/

Laser diodes

The basic construction of a laser diode is shown in Figure (b). A pn junction is formed by two layers of doped gallium arsenide. The length of the pn junction bears a precise relationship with the wavelength of the light to be emitted. There is a highly reflective surface at one end of the pn junction and a partially reflective surface at the other end, forming a resonant cavity for the photons. External leads provide the anode and cathode connections.



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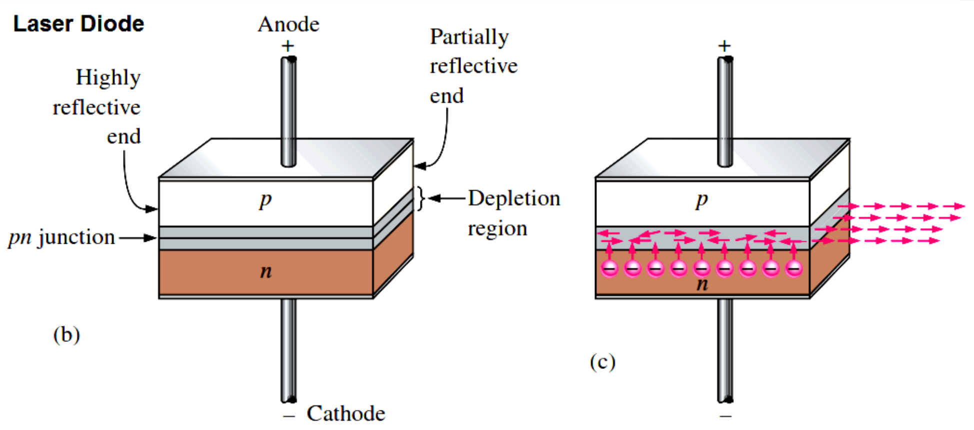
Laser diodes



The basic operation is as follows. The laser diode is forward-biased by an external voltage source. As electrons move through the junction, recombination occurs just as in an ordinary diode. As electrons fall into holes to recombine, photons are released. A released photon can strike an atom, causing another photon to be released. As the forward current is increased, more electrons enter the depletion region and cause more photons to be emitted. Eventually some of the photons that are randomly drifting within the depletion region strike the reflected surfaces perpendicularly. These reflected photons move along the depletion region, striking atoms and releasing additional photons due to the avalanche effect.

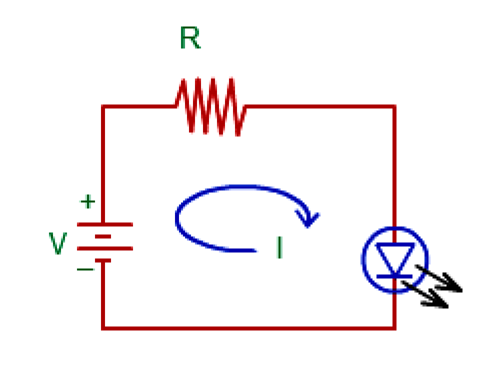
This back-and-forth movement of photons increases as the generation of photons "snow-balls" until a very intense beam of laser light is formed by the photons that pass through the partially reflective end of the pn junction. Each photon produced in this process is identical to the other photons in energy level, phase relationship, and frequency. So a single wavelength of intense light emerges from the laser diode, as indicated in Figure (c). Laser diodes have a threshold level of current above which the laser action occurs and below which the diode behaves essentially as an LED, emitting incoherent light.

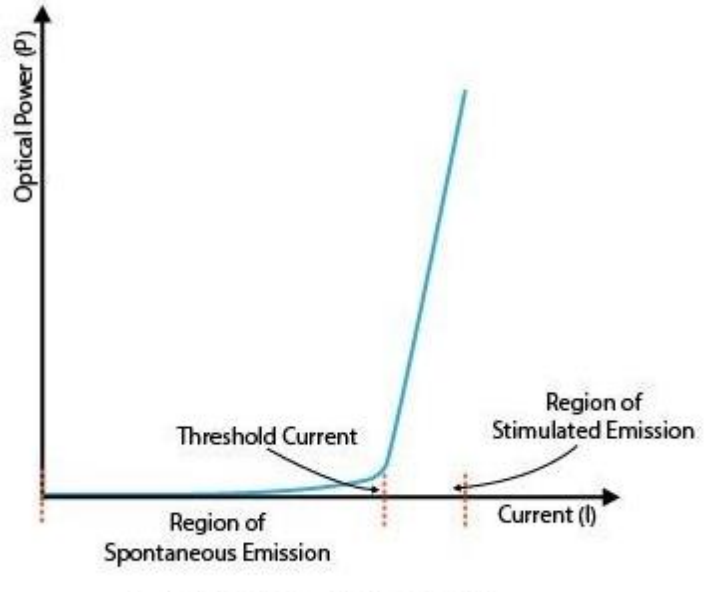
https://instrumentationtools.com/laser-diode-working-principle/

Laser diodes

Laser Diode P-I Characteristics

The below diagram is a graphical plot between output optical power on y-axis and the current input to the laser diode on x-axis. One of the important characteristics of a laser diode is that the threshold. It is given that, the lasing action will not takes place until a minimum power is applied to the material. This is illustrated in the following figure





LASER DIODE P-I GRAPH

As we increase the current flow to the laser diode, the optical power of output light gradually increases up to a certain threshold. Until this point, most of the light emitted is due to spontaneous emission. Above this threshold current, the process of stimulated emission increases. This causes the power of output light to increase a lot even for smaller increases in input current. The output optical power also depends on temperature and it reduces with decrease in temperature.

https://www.electronicshub.org/laser-diode-working-structure-types-uses/#:~:text=A%20Laser%20Diode%20is%20a,the%20same%20frequency%20and%20phase.&text=And%20since%20a%20p%2Dn%20junction,named%20as%20a%20laser%20diode.

Laser diode

The key to the laser diode operation occurs at the junction of the highly doped p and n type regions. In a normal p-n junction current flows across the p-n junction. This action can occur because the holes from the p-type region and the electrons from the n-type region combine. With an electromagnetic wave (in this instance light) in passing through the laser diode junction diode junction it is found that the photo-emission process occurs. Here the photons release further photons of light occurs when they strike electrons during the recombination of holes and electrons occurs.

Naturally there is some absorption of the light, resulting in the generation of holes and electrons but there is an overall gain in level.

The structure of the laser diode creates an optical cavity in which the light photons have multiple reflections. When the photons are generated only a small number are able to leave the cavity. In this way when one photon strikes an electron and enables another photon to be generated the process repeats itself and the photon density or light level starts to build up. It is in the design of better optical cavities that much of the current work on lasers is being undertaken. Ensuring the light is properly reflected is the key to the operation of the device.

https://ecee.colorado.edu/~bart/book/book/chapter4/ch4_6.htm#fig4_6_6

Laser Diode

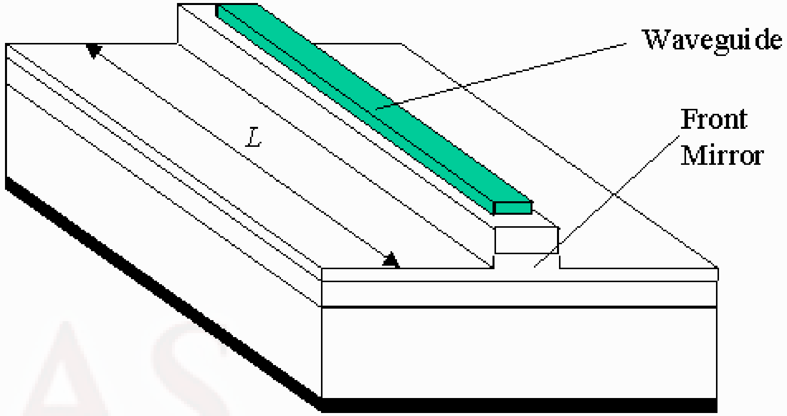
The stimulated emission process yields an increase in photons as they travel along the waveguide. Combined with the waveguide losses, stimulated emission yields a net gain per unit length, *g*. The number of photons can therefore be maintained if the roundtrip amplification in a cavity of length, *L*, including the partial reflection at the mirrors with reflectivity R_1 and R_2 equals unity.

This yields the following lasing condition:

$$\text{Roundtrip amplification} = e^{2gL} R_1 R_2 = 1$$

If the roundtrip amplification is less than one, then the number of photons steadily decreases. If the roundtrip amplification is larger than one, the number of photons increases as the photons travel back and forth in the cavity. The gain required for lasing therefore equals:

$$g = \frac{1}{2L} \ln \frac{1}{R_1 R_2}$$



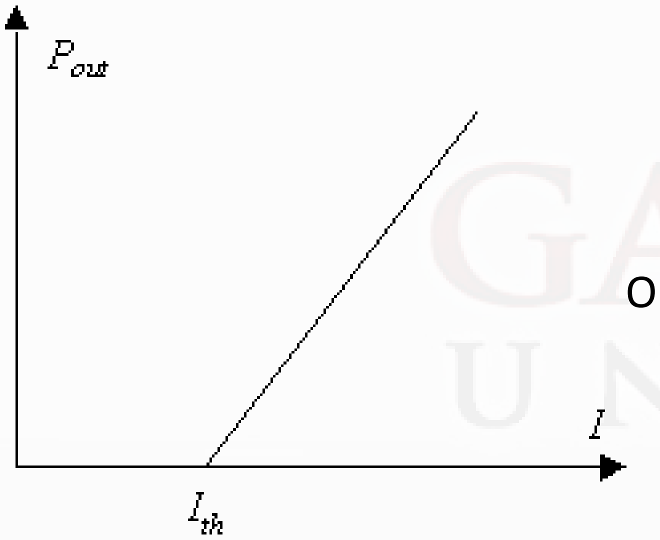
Initially, the gain is negative if no current is applied to the laser diode as absorption dominates in the waveguide.

https://ecee.colorado.edu/~bart/book/book/chapter4/ch4_6.htm#fig4_6_6

As the laser current is increased, the absorption first decreases and the gain increases. The current for which the gain satisfies the lasing condition is the threshold current of the laser, I_{th}. Below the threshold current very little light is emitted by the laser structure. For an applied current larger than the threshold current, the output power, P_{out}, increases linearly with the applied current, as each additional incoming electron-hole pair is converted into an additional photon. The output power therefore equals:

$$P_{out} = \eta \frac{h\nu}{q}(I - I_{th})$$

where *h*n is the energy per photon. The factor, h, indicates that only a fraction of the generated photons contribute to the output power of the laser as photons are partially lost through the other mirror and throughout the waveguide.



Output power from a laser diode versus the applied current.

https://ecee.colorado.edu/~bart/book/book/chapter4/ch4_6.htm#fig4_6_6

Applications of Laser Diode

Applications

Telecommunications, scanning and spectrometry

Laser diodes find wide use in telecommunication as easily modulated and easily coupled light sources for fiber optics communication. They are used in various measuring instruments, such as rangefinders. Another common use is in barcode readers. Visible lasers, typically red but later also green, are common as laser pointers. Both low and high-power diodes are used extensively in the printing industry both as light sources for scanning (input) of images and for very high-speed and high-resolution printing plate (output) manufacturing. Infrared and red laser diodes are common in CD players, CD-ROMs and DVD technology. Violet lasers are used in HD DVD and Blu-ray technology. Diode lasers have also found many applications in laser absorption spectrometry (LAS) for high-speed, low-cost assessment or monitoring of the concentration of various species in gas phase. High-power laser diodes are used in industrial applications such as heat treating, cladding, seam welding and for pumping other lasers, such as diode-pumped solid-state lasers.
Uses of laser diodes can be categorized in various ways. Most applications could be served by larger solid-state lasers or optical parametric oscillators, but the low cost of mass-produced diode lasers makes them essential for mass-market applications. Diode lasers can be used in a great many fields; since light has many different properties (power, wavelength, spectral and beam quality, polarization, etc.) it is useful to classify applications by these basic properties.

Many applications of diode lasers primarily make use of the "directed energy" property of an optical beam. In this category, one might include the laser printers, barcode readers, image scanning, illuminators, designators, optical data recording, combustion ignition, laser surgery, industrial sorting, industrial machining, and directed energy weaponry. Some of these applications are well-established while others are emerging

https://en.wikipedia.org/wiki/Laser_diode

Medical uses

Laser medicine: medicine and especially dentistry have found many new uses for diode lasers. The shrinking size and cost of the units and their increasing user friendliness makes them very attractive to clinicians for minor soft tissue procedures. Diode wavelengths range from 810 to 1,100 nm, are poorly absorbed by soft tissue, and are not used for cutting or ablation. Soft tissue is not cut by the laser's beam, but is instead cut by contact with a hot charred glass tip. The laser's irradiation is highly absorbed at the distal end of the tip and heats it up to 500 °C to 900 °C. Because the tip is so hot, it can be used to cut soft-tissue and can
cause hemostasis through cauterization and carbonization. Diode lasers when used on soft tissue can cause extensive collateral thermal damage to surrounding tissue.

As laser beam light is inherently coherent, certain applications utilize the coherence of laser diodes. These include interferometric distance measurement, holography, coherent communications, and coherent control of chemical reactions.

Laser diodes are used for their "narrow spectral" properties in the areas of range-finding, telecommunications, infra-red countermeasures, spectroscopic sensing, generation of radio-frequency or terahertz waves, atomic clock state preparation, quantum key cryptography, frequency doubling and conversion, water purification (in the UV), and photodynamic therapy (where a particular wavelength of light would cause a substance such as porphyrin to become chemically active as an anti-cancer agent only where the tissue is illuminated by light).

Laser diodes are used for their ability to generate ultra-short pulses of light by the technique known as "mode-locking." Areas of use include clock distribution for high-performance integrated circuits, high-peak-power sources for laser-induced breakdown spectroscopy sensing, arbitrary waveform generation for radio-frequency waves, photonic sampling for analog-to-digital conversion, and optical code-division-multiple-access systems for secure communication.

https://en.wikipedia.org/wiki/Laser_diode

Questions

Study Questions

1. Explain laser diode structure and working.
2. Write the Difference between laser diode and LED
3. What is the mathematical expression which decide the lasing action
4. Draw the power and current graph for laser diode and explain threshold current
5. Describe the optical cavity in laser diode